AD-A127 423 FATIGUE CRACK PROPAGATION IN AN HSLA STEEL (MF-80) IN AIR AND IN SALT WATER(U) NAVAL RESEARCH LAB WASHINGTON DC S J GILL ET AL. 21 APR 83 NRL-MR-5048

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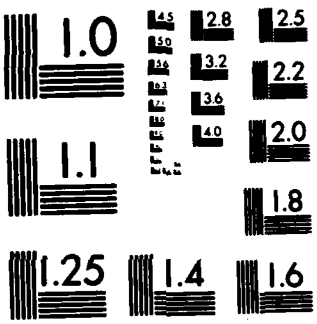
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20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

Fatigue crack propagation was studied in MF-80 HSLA steel in ambient room air and in 3.5 percent NaCl salt water. Region-II fatigue crack growth rate (da/dN) data were obtained at two load ratios, R = 0.10 and R = 0.67. da/dN values were found to be affected by both load ratio and environment, with the greatest effect being caused by the combination of high load ratio and salt water environment. Overall, the results of this study suggest that MF-80 HSLA steel may have slightly less Region-II fatigue crack propagation resistance than other high-strength steels of comparable strength.

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CONTENTS

FATIGUE CRACK PROPAGATION IN AN HSLA STEEL (MF-80) IN AIR AND IN SALT WATER

S. J. Gill and T. W. Crooker

Mechanics of Materials Branch
Material Science and Technology Division
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INTRODUCTION

HSLA steels are currently under investigation as candidate materials for new naval ship structures. Essentially, HSLA steels are carbon-manganese steels with very small additions of vanadium and/or columbium for grain refinement and precipitation hardening. Potentially, HSLA steels offer the possibility of attaining high strength, high fracture toughness and good weldability without resorting to extensive use of scarce or expensive alloying elements.

The development of favorable strength and toughness is quite dependent on microstructural refinement [1,2]. However, recent studies have shown that microstructural refinement can be detrimental to fatigue crack propagation resistance in steels [3]. This investigation was undertaken to examine this aspect of the fatigue behavior of MF-80 HSLA steel base material.

MATERIALS AND EXPERIMENTAL PROCEDURES

The material used in this study was 6.4 mm thick MF-80 (TM) steel. The composition of this steel, as given by the producer, is shown in Table 1. In addition to the carbon, manganese and columbium, or vanadium, present in all HSLA steels, this steel contains more than a trace amount of silicon. The result is that the alloy shows good ductility despite its high strength [4]. MF-80 steel of this thickness is typically aluminum killed and hot rolled to a reduction of at least 50% at 900 to 925°C, cooled at rates between 8°C and 75°C per second and coiled at 650°C. The coils are then air cooled [4,5]. Mechanical properties of the plate are given in Table 2.

The microstructure of the steel is shown in Figure 1. Sections of the longitudinal, transverse and short transverse planes were examined and no significant differences due to orientation were found. The microstructure consisted of equiaxed ferrite. It was very fine grained, with a grain size corresponding roughly to ASTM grain size number 8 [6].

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Fatigue crack growth rate tests were conducted in ambient room air and in flowing 3.5 percent NaCl aqueous solution. Tests in air were conducted in accordance with ASTM E647-81 [7] and tests in salt water were conducted in accordance with a proposed Navy standard test method [8]. A schematic view of the test system is shown Figure 2.

Wedge-opening-loaded (WOL) specimens with planar dimensions corresponding to the 2T configuration were used. Width, (W) was 129.5 mm and thickness (B) was 6.4 mm. In each case, notches were machined in the T-L orientation, that is, parallel to the final rolling direction of the plate [9]. The test specimen is shown in Figure 3.

Replicate specimens were tested at load ratios (minimum load/maximum load) of R = 0.1 and 0.67 in both environments. The cyclic loading frequency for tests conducted in air was 5.0 Hz and for tests conducted in salt water the frequency was 0.5 Hz. For steels of the type studied in this investigation, evidence shows that crack growth rates in air are not affected by cyclic loading frequency [10]. However, for virtually all steels crack growth rates in salt water tend to increase with decreasing cyclic frequency [10,11]. Under freely corroding conditions, a salt water environment generally has little effect on crack growth rates at frequencies greater than 1 Hz. The frequency of 0.5 Hz used for the salt water tests in this investigation was chosen because it falls within the range of frequencies where environmental sensitivity is known to occur and it approximates cyclic loading rates known to occur in ship structures.

Crack length measurements were made by means of a crack-opening-displacement (COD) technique [12]. Crack length (a) versus cycles (N) data were reduced to a crack growth rate (da/dN) versus stress-intensity range (ΔK) format by means of a BASIC language computer program on a Tektronix 4051 computer per ASTM E647-81.

RESULTS AND DISCUSSION

Values of da/dN-versus-ΔK data for each specimen tested are plotted in Figures 4 and 5, and are tabulated in Appendix 1. Data generated in air are shown in Figure 4 and salt water data are shown in Figure 5. The da/dN-versus-ΔK data indicate that crack growth rates in MF-80 HSLA steel are sensitive to both load ratio and corrosion, with the greatest effects resulting from a combination of the two factors. This is illustrated by the fact that da/dN values in salt water at R = 0.67 are approximately five times greater than in air at R = 0.1. This is consistent with previous results obtained on HY-100 steel [13].

A straight line was fitted to the data from each specimen. The form of the equation used to describe these straight lines was the Paris power law [14],

$$\frac{da}{dN} = C\,(\Delta K)^n.$$

Calculated values of the constants C and n are given in Table 3 where they are compared to upper bounds found for two broad classes of steels [15].

Figure 6 shows a comparison between the air environment data for MF-80 HSLA steel and two other high-strength ship steels, HS and HY-100 [13]. For the most part, fatigue crack growth rates are faster in the HSLA steel, by factors ranging from approximately two to four. Typically, Region-II fatigue crack growth rates in steels tend to exhibit marked similarities with little variation from alloy to alloy [15]. Where significant differences do occur, most often it is in the near-threshold Region I, and there it can be modeled on the basis of yield strength and grain size considerations [3]. Based on these factors, the increased crack growth rates observed in the HSLA steel may be due to the finer microstructure which is characteristic of this material.

CONCLUSIONS

- Fatigue crack growth rates in MF-80 HSLA steel are affected by both load ratio and a salt water environment.
- The combination of a high load ratio (R = 0.67) and a salt water environment produces the fastest crack growth rates.
- Comparisons with two other high-strength ship steels, show that MF-80 HSLA steel exhibits less resistance to Region-II fatigue crack growth than HS or HY-100.

ACKNOWLEDGMENTS

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REFERENCES

[1] R. R. Preston, "HSLA Metallurgy in Europe", Journal of Metals, Vol. 29, No. 1, January 1977, pp. 9-16.

[2] A. D. Wilson, "The Fatigue and Toughness Properties of a C-Mn-Cb Plate Steel", Journal of Engineering Materials and Technology, Vol. 102, No. 3, July 1980, pp. 269-279.

[3] G. R. Yoder, L. A. Cooley, and T. W. Crooker, "A Critical Analysis of Grain-Size and Yield-Strength Dependence of Near-Threshold Fatigue-Crack Growth in Steels", NRL Memorandum Report 4576, July 15, 1981.

[4] S. J. Matas et al., "High Strength Low Alloy Steel", U.S. Patent 3,997,372, December 14, 1976.

[5] G. J. Klems, Republic Steel Corporation, private communication.

[6] E112-81, "Standard Methods for Estimating the Average Grain Size of Metals", 1981 Annual Book of ASTM Standards, Part 11, American Society for Testing and Materials, 1981, pp. 363-397.

[7] E647-81, "Standard Test Method for Constant-Load-Amplitude Fatigue Crack Growth Rates Above 10^{-8}m/Cycle", 1981 Annual Book of ASTM Standards, Part 10, American Society for Testing and Materials, 1981, pp. 765-783.

[8] T. W. Crooker, F. D. Bogar, and G. R. Yoder, "Standard Method of Test for Constant-Load-Amplitude Fatigue Crack Growth Rates in Marine Environments", NRL Memorandum Report 4594, August 6, 1981.

[9] R. J. Goode, "Identification of Fracture Plane Orientation", Materials Research and Standards, Vol. 12, No. 9, September 1972, p. 31.

[10] S. T. Rolfe and J. M. Barsom, Fracture and Fatigue Control in Structures, Prentice-Hall, Inc., Englewood Cliffs, N. J., 1977.

[11] O. Vosikovsky, "Effects of Mechanical and Environmental Variables on Fatigue Crack Growth Rates in Steel. A Summary of Work Done at CANMET", Canadian Metallurgical Quarterly, Vol. 19, 1980, pp. 87-97.

[12] G. R. Yoder, L. A. Cooley, and T. W. Crooker, "Procedures for Precision Measurement of Fatigue Crack Growth Rate Using Crack-Opening Displacement Techniques", Fatigue Crack Growth Measurement and Data Analysis, ASTM STP 738, S. J. Hudak, Jr. and R. J. Bucci, Eds., American Society for Testing and Materials, 1981, pp. 85-102.

[13] S. J. Gill and T. W. Crooker, "Load Ratio and Environmental Effects on Fatigue Crack Growth Rates for Several Ship Steels", NRL Memorandum Report (pending).

[14] P. C. Paris and F. Erdogan, "A Critical Analysis of Crack Propagation Laws", Journal of Basic Engineering, Vol. 85, ASME Transactions, Series D, No. 4, December 1963, p. 528-534.

[15] J. M. Barsom, "Fatigue-Crack Propagation in Steels of Various Yield Strengths", Journal of Engineering for Industry, Vol. 93, ASME Transactions, Series B, No. 4, November 1971, pp. 1190-1196.

TABLE 1

Chemical Composition

Element	Weight percent
Carbon	0.07
Manganese	1.46
Phosphorus	0.009
Sulfur	0.012
Silicon	0.30
Vanadium	0.085
Columbium	0.10

TABLE 2

Mechanical Properties

Property	Values Obtained
0.2% Offset	
Tensile Yield	
Strength (MPa)	653
(ksi)	94.8
Ultimate	
Tensile	
Strength (MPa)	742
(ksi)	107.7
Hardness	R_B 90

TABLE 3

Calculated Values of Paris Power Law Constants C and n

Er onment	Steel	Load Ratio	ΔK Range MPa$\sqrt{m}$	C $\frac{m/cycle}{(MPa\sqrt{m})^n}$	n	Correlation Coefficient
Air	MF-80 HSLA	.1	14-90	5.06×10^{-11}	2.46	.981
		.67	12-43	2.42×10^{-11}	2.88	.992
	Martensitic	0 to 0.7	5-100	1.35×10^{-10}	2.25	-
	Ferritic-Pearlitic	0 to 0.7	15-60	6.91×10^{-12}	3.00	-
3.5% NaCl	MF-80 HSLA	.1	15-86	4.25×10^{-10}	2.05	.992
		.67	13-43	4.16×10^{-10}	2.25	.993

$$C\left(\frac{in./cycle}{(ksi\sqrt{in})^n}\right) = C\left(\frac{m./cycle}{(MPa\sqrt{m})^n}\right) X \frac{39.37}{(.91)^n}$$

Figure 1 - Microstructure of MF-80 HSLA steel viewed in short transverse direction

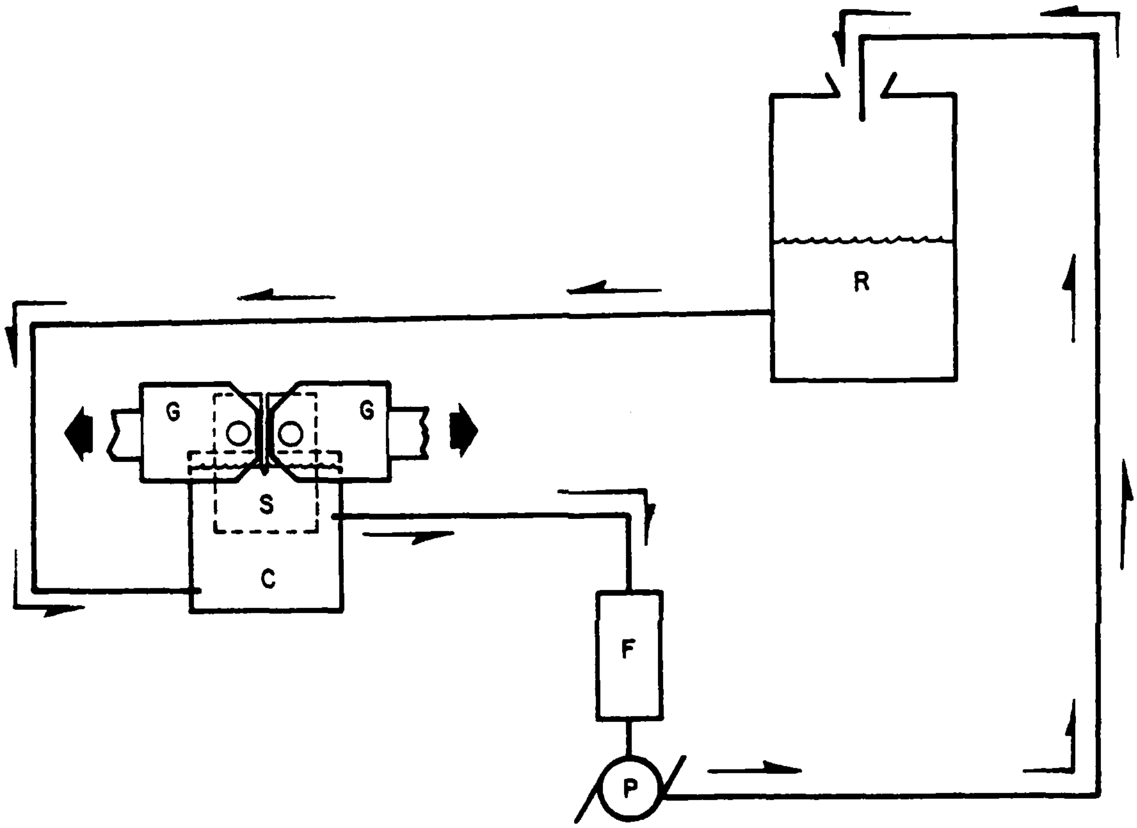
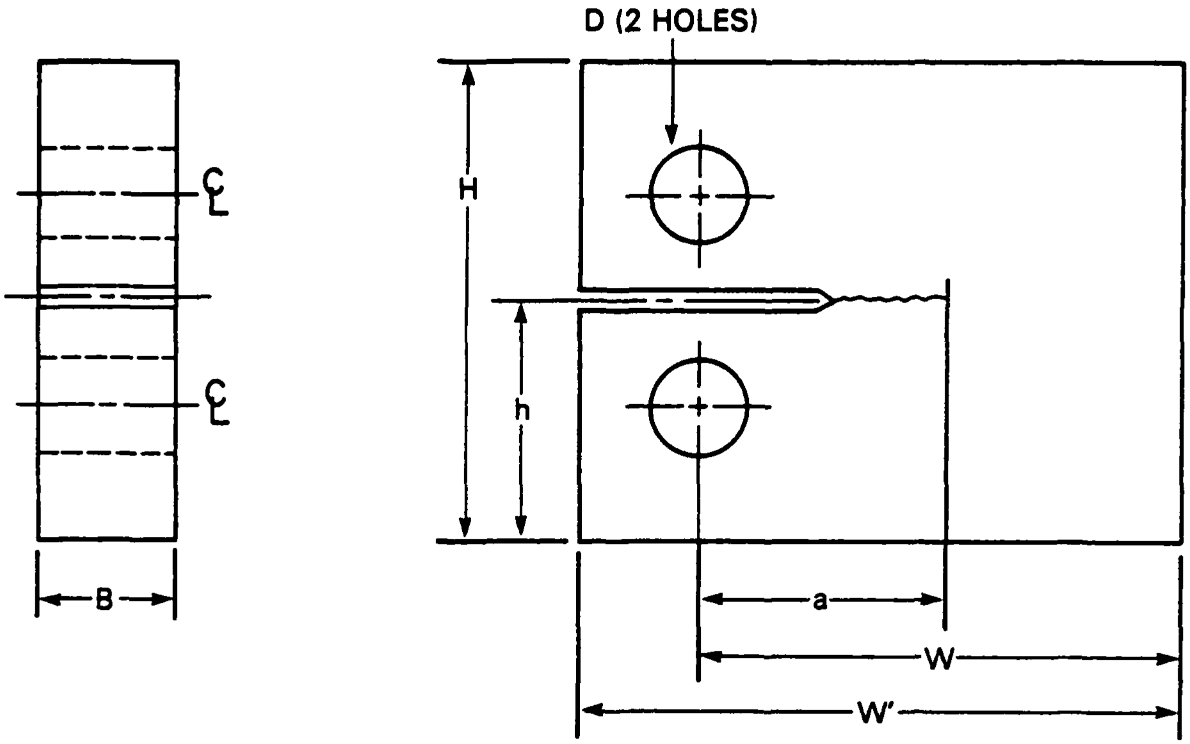


Figure 2 - Environmental circulation system showing the WOL test specimen (S), grips (G), environmental chamber (C), reservoir (R), pump (P), and filter (F).



	inches	mm.
W	5.10	129.54
W'	6.40	162.56
a	variable	variable
h	2.48	62.99
H	4.96	125.98
D	1.00	25.40
B	variable	variable

Figure 3 - 2T wedge-opening-loaded specimen

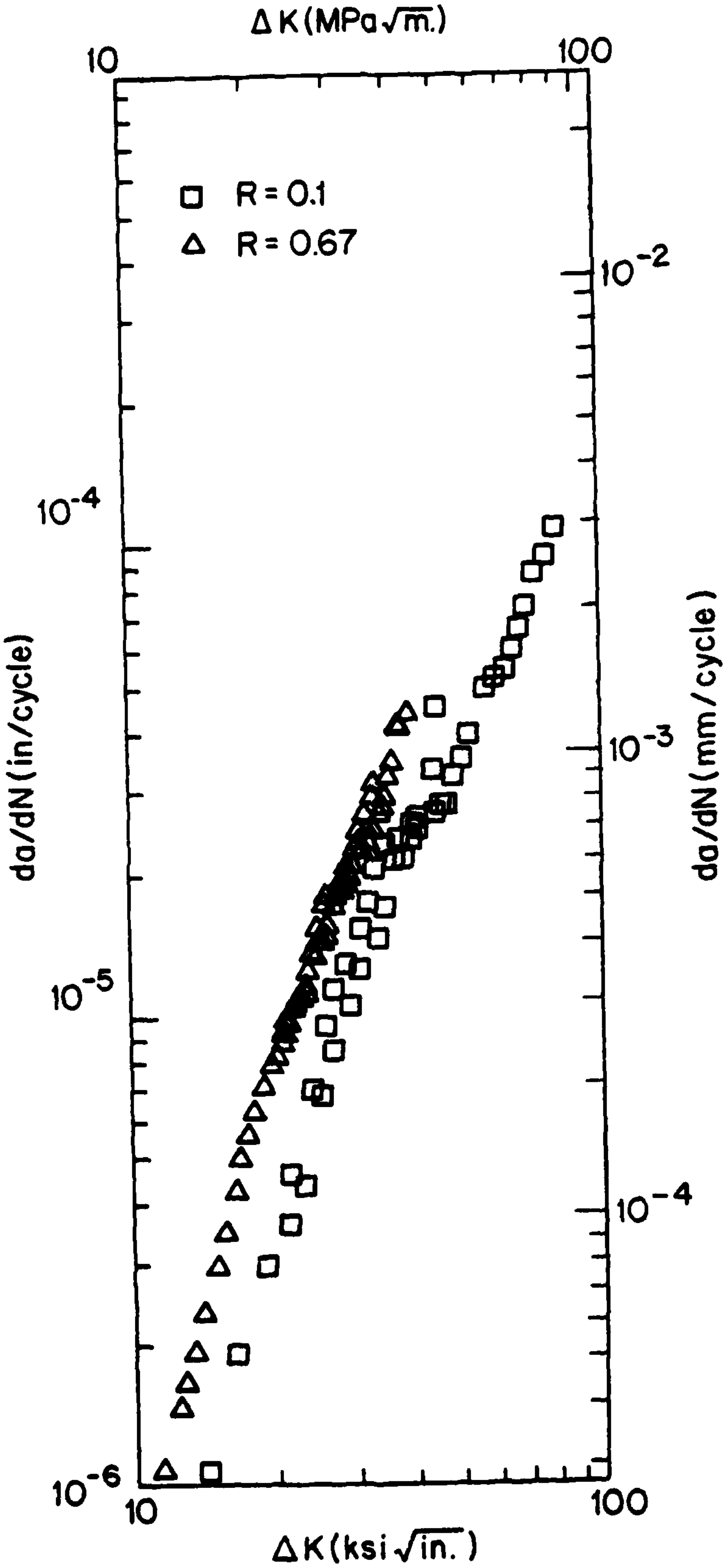


Figure 4 - Fatigue crack growth rate data for MF-80 HSIA steel in air

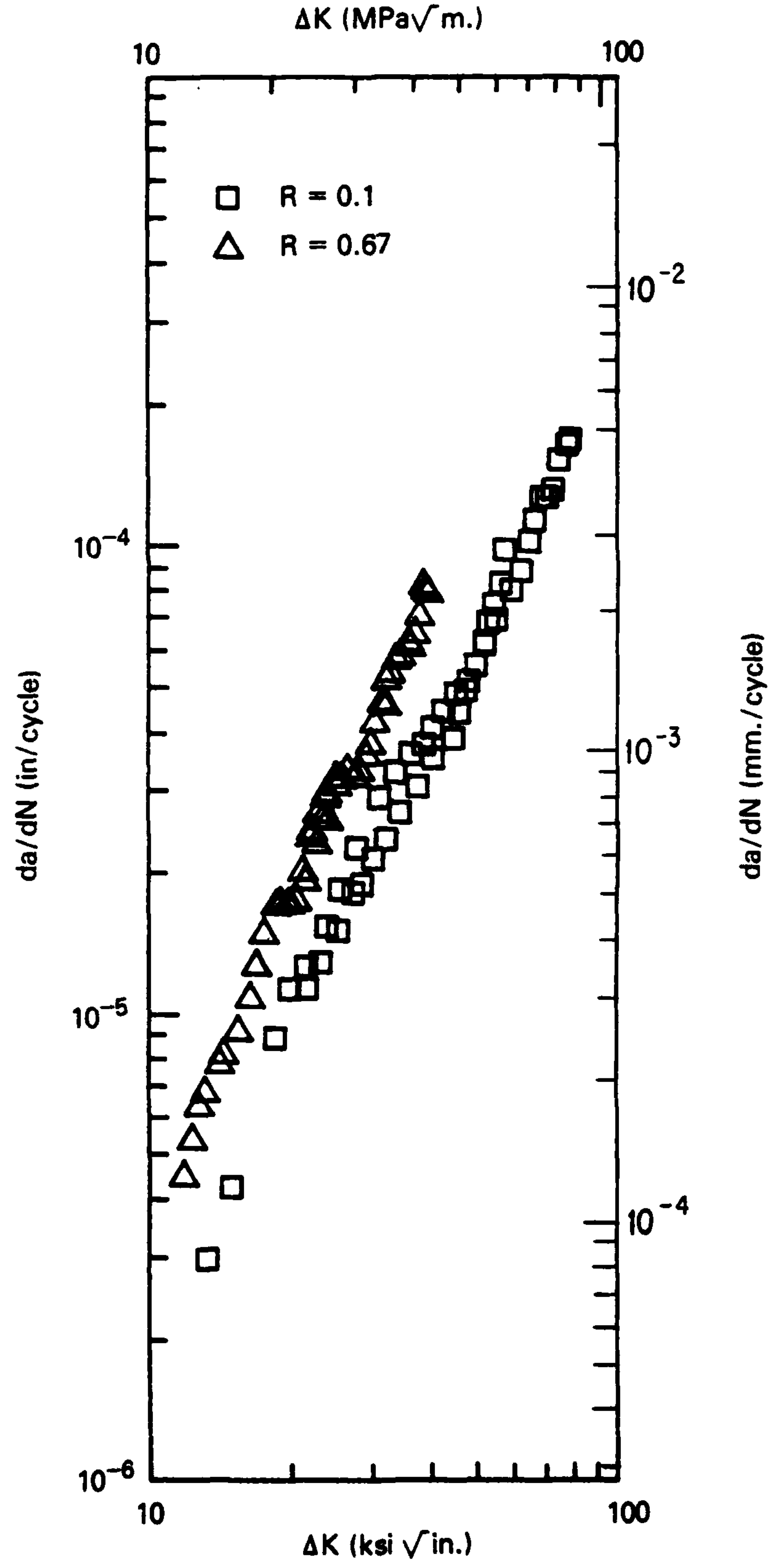


Figure 5 - Fatigue crack growth rate data for MF-80 HSLA steel in 3.5% NaCl

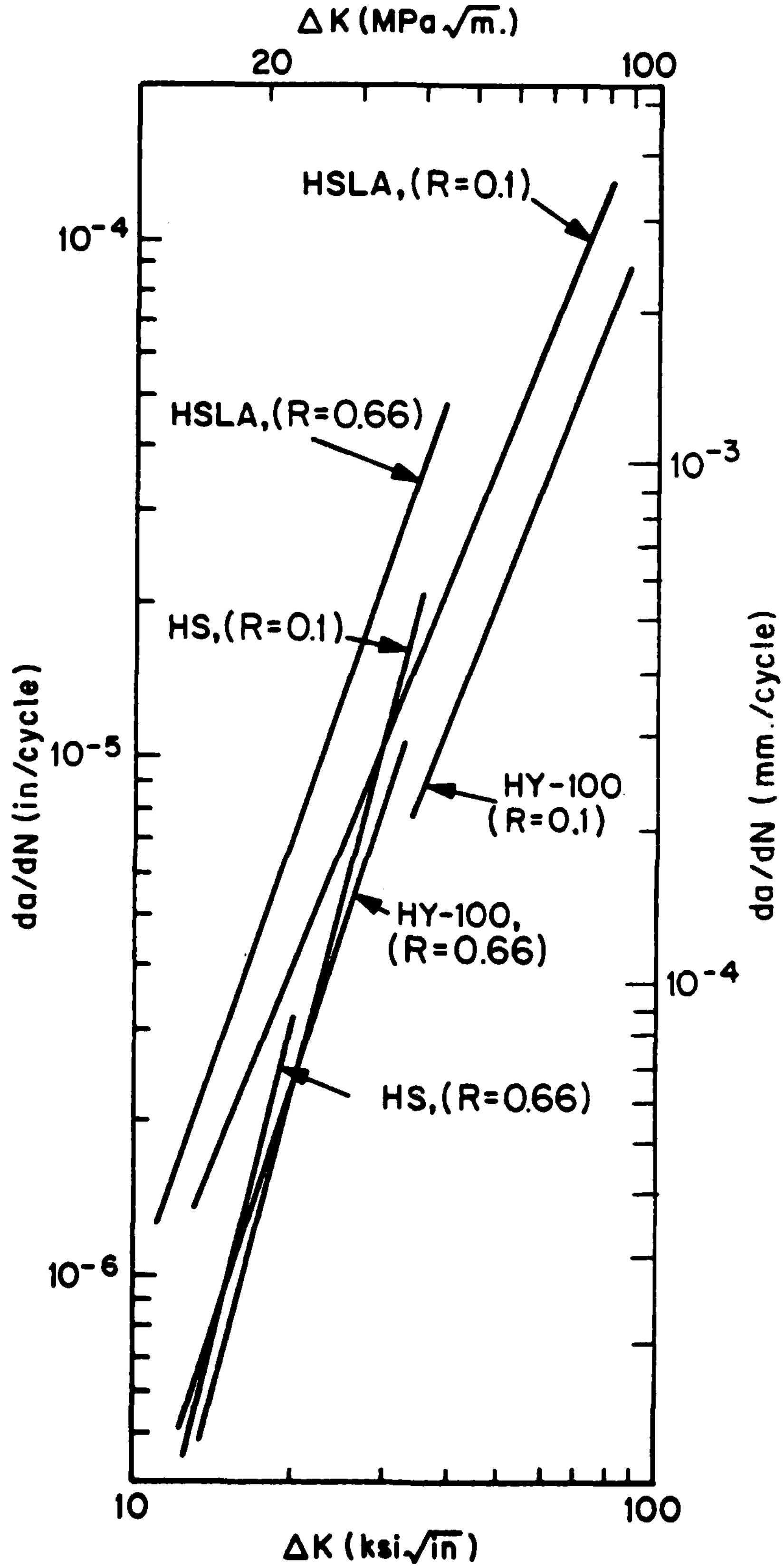


Figure 6 - Fatigue crack growth rate data for HSLA, HS and HY-100 steels in air

APPENDIX 1

Tabulated Fatigue Crack Growth Rate Data

HSLA-1
R= 0.1
TEMP. AMBIENT
FREQUENCY 5 HZ
ENVIRONMENT AIR

7 PT. POLYNOMIAL FIT

(1ST 3 PTS. FIT BY SECANT METHOD)

OBS.	CRACK LENGTH		CYCLES	DA/DN PER CYCLE		DELTA K	
	IN.	MM.		IN.	MM.	KSI $\sqrt{IN.}$	MPA $\sqrt{M.}$
2	1.825	46.3	55000	3.608E-006	9.163E-005	21.09	23.15
3	2.010	51.1	95000	4.332E-006	1.100E-004	22.80	25.04
4	2.227	56.6	115000	6.789E-006	1.724E-004	25.06	27.52
5	2.361	60.0	135000	8.358E-006	2.123E-004	26.67	29.28
6	2.536	64.4	155000	1.053E-005	2.676E-004	29.07	31.92
7	2.641	67.1	165000	1.256E-005	3.190E-004	30.74	33.75
8	2.777	70.5	175000	1.460E-005	3.708E-004	33.22	36.47
9	2.849	72.4	180000	1.694E-005	4.304E-004	34.70	38.10
10	2.938	74.6	185000	2.140E-005	5.436E-004	36.71	40.30
11	2.991	76.0	187500	2.157E-005	5.478E-004	38.02	41.75
12	3.049	77.4	190000	2.357E-005	5.986E-004	39.58	43.46
13	3.099	78.7	192000	2.508E-005	6.371E-004	41.02	45.04
14	3.203	81.4	196000	2.703E-005	6.864E-004	44.39	48.74
15	3.256	82.7	198000	2.807E-005	7.131E-004	46.28	50.82
16	3.281	83.3	199000	2.830E-005	7.188E-004	47.25	51.88
17	3.314	84.2	200000	3.219E-005	8.176E-004	48.54	53.29
18	3.370	85.6	202000	3.491E-005	8.868E-004	50.97	55.96
19	3.404	86.5	203000	3.935E-005	9.995E-004	52.50	57.64
20	3.492	88.7	205000	4.959E-005	1.260E-003	56.99	62.57
21	3.547	90.1	206000	5.196E-005	1.320E-003	60.08	65.97
22	3.602	91.5	207000	5.426E-005	1.378E-003	63.56	69.79
23	3.630	92.2	207500	6.017E-005	1.528E-003	65.45	71.86
24	3.658	92.9	208000	6.647E-005	1.688E-003	67.44	74.05
25	3.689	93.7	208500	7.361E-005	1.870E-003	69.74	76.58
26	3.730	94.7	209000	8.717E-005	2.214E-003	73.04	80.20
27	3.778	96.0	209500	9.362E-005	2.378E-003	77.30	84.88
28	3.826	97.2	210000	1.080E-004	2.742E-003	81.91	89.94

HSLA-2
R= 0.666
TEMP. AMBIENT
FREQUENCY 5 HZ
ENVIRONMENT AIR

7 PT POLYNOMIAL FIT

(1ST 3 PTS. FIT BY SECANT METHOD)

OBS.	CRACK LENGTH		CYCLES	DA/DN PER CYCLE		DELTA K	
	IN.	MM.		IN.	MM.	KSI$\sqrt{IN.}$	MPA$\sqrt{M.}$
3	1.865	47.4	25000	8.815E-006	2.239E-004	21.05	23.12
4	1.955	49.7	30000	9.751E-006	2.477E-004	21.87	24.01
5	2.008	51.0	35000	1.054E-005	2.678E-004	22.37	24.56
6	2.062	52.4	40000	1.110E-005	2.819E-004	22.89	25.13
7	2.119	53.8	45000	1.170E-005	2.973E-004	23.46	25.75
8	2.180	55.4	50000	1.255E-005	3.187E-004	24.09	26.45
9	2.242	57.0	55000	1.351E-005	3.432E-004	24.78	27.21
10	2.313	58.8	60000	1.444E-005	3.668E-004	25.60	28.10
11	2.349	59.7	62500	1.493E-005	3.793E-004	26.03	28.58
12	2.380	60.4	64500	1.567E-005	3.980E-004	26.41	29.00
13	2.444	62.1	68500	1.731E-005	4.396E-004	27.25	29.92
14	2.478	62.9	70500	1.848E-005	4.693E-004	27.71	30.43
15	2.516	63.9	72500	1.905E-005	4.840E-004	28.25	31.02
16	2.547	64.7	74000	1.971E-005	5.006E-004	28.71	31.52
17	2.587	65.7	76000	2.068E-005	5.253E-004	29.31	32.18
18	2.627	66.7	78000	2.120E-005	5.385E-004	29.96	32.89
19	2.692	68.4	81000	2.253E-005	5.724E-004	31.05	34.09
20	2.714	68.9	82000	2.370E-005	6.019E-004	31.44	34.52
21	2.764	70.2	84000	2.468E-005	6.268E-004	32.35	35.53
22	2.790	70.9	85000	2.502E-005	6.356E-004	32.85	36.07
23	2.813	71.5	86000	2.539E-005	6.450E-004	33.32	36.59
24	2.840	72.1	87000	2.699E-005	6.856E-004	33.86	37.18
25	2.867	72.8	88000	2.814E-005	7.148E-004	34.44	37.82
26	2.894	73.5	89000	2.941E-005	7.470E-004	35.04	38.47
27	2.925	74.3	90000	3.227E-005	8.198E-004	35.75	39.25
28	2.958	75.1	91000	3.469E-005	8.812E-004	36.53	40.11
29	2.994	76.0	92000	4.188E-005	1.064E-003	37.40	41.07
30	3.016	76.6	92500	4.156E-005	1.056E-003	37.98	41.70
31	3.061	77.8	93500	4.435E-005	1.126E-003	39.20	43.04

HSLA-3
R= 0.1
TEMP. AMBIENT
FREQUENCY 0.5 HZ
ENVIRONMENT 3.5 % NACL

7 PT. POLYNOMIAL FIT

(1ST 3 PTS. FIT BY SECANT METHOD)

OBS.	CRACK LENGTH		CYCLES	DA/DN PER CYCLE		DELTA K	
	IN.	MM.		IN.	MM.	KSI $\sqrt{IN.}$	MPA $\sqrt{M.}$
2	1.902	48.3	20000	1.128E-005	2.864E-004	21.58	23.69
3	2.051	52.1	30000	1.281E-005	3.253E-004	22.98	25.23
4	2.252	57.2	40000	1.498E-005	3.804E-004	25.10	27.56
5	2.407	61.1	50000	1.794E-005	4.556E-004	27.00	29.64
6	2.497	63.4	55000	1.883E-005	4.783E-004	28.23	30.99
7	2.594	65.9	60000	2.136E-005	5.426E-004	29.69	32.59
8	2.700	68.6	65000	2.354E-005	5.977E-004	31.47	34.55
9	2.822	71.7	70000	2.696E-005	6.847E-004	33.80	37.11
10	2.965	75.3	75000	3.073E-005	7.806E-004	37.02	40.65
11	3.078	78.2	78700	3.518E-005	8.937E-004	40.02	43.94
12	3.207	81.4	82000	3.882E-005	9.860E-004	44.03	48.39
13	3.241	82.3	83000	4.382E-005	1.113E-003	45.29	49.73
14	3.286	83.5	84000	4.915E-005	1.248E-003	46.98	51.59
15	3.331	84.6	85000	5.538E-005	1.407E-003	48.81	53.59
16	3.391	86.1	86000	6.261E-005	1.590E-003	51.43	56.47
17	3.457	87.8	87000	6.961E-005	1.768E-003	54.60	59.96
18	3.530	89.7	88000	8.020E-005	2.037E-003	58.55	64.29
19	3.574	90.8	88500	8.818E-005	2.240E-003	61.20	67.20
20	3.619	91.9	89000	1.021E-004	2.594E-003	64.08	70.36
21	3.641	92.5	89250	1.135E-004	2.884E-003	65.58	72.00
22	3.672	93.3	89500	1.268E-004	3.219E-003	67.82	74.47
23	3.700	94.0	89700	1.270E-004	3.227E-003	69.98	76.83
24	3.725	94.6	89900	1.314E-004	3.338E-003	71.97	79.03
25	3.750	95.3	90100	1.522E-004	3.866E-003	74.08	81.34
26	3.782	96.1	90300	1.637E-004	4.158E-003	76.94	84.48
27	3.799	96.5	90400	1.688E-004	4.287E-003	78.54	86.23

HSLA-4
R= 0.666
TEMP. AMBIENT
FREQUENCY 0.5 HZ
ENVIRONMENT 3.5 % NACL

7 PT. POLYNOMIAL FIT

(1ST 3 PTS. FIT BY SECANT METHOD)

OBS.	CRACK LENGTH		CYCLES	DA/DN PER CYCLE		DELTA K	
	IN.	MM.		IN.	MM.	KSI$\sqrt{IN.}$	MPA$\sqrt{M.}$
2	1.910	48.5	15000	2.021E-005	5.134E-004	21.42	23.52
3	1.985	50.4	17000	2.392E-005	6.076E-004	22.10	24.27
4	2.055	52.2	19000	2.319E-005	5.890E-004	22.77	25.00
5	2.150	54.6	23000	2.611E-005	6.631E-004	23.73	26.06
6	2.201	55.9	25000	2.956E-005	7.509E-004	24.27	26.65
7	2.262	57.4	27000	3.223E-005	8.185E-004	24.95	27.39
8	2.298	58.4	28000	3.088E-005	7.844E-004	25.36	27.85
9	2.330	59.2	29000	3.223E-005	8.187E-004	25.75	28.27
10	2.395	60.8	31000	3.342E-005	8.489E-004	26.55	29.16
11	2.459	62.5	33000	3.203E-005	8.135E-004	27.40	30.08
12	2.491	63.3	34000	3.199E-005	8.125E-004	27.83	30.56
13	2.523	64.1	35000	3.310E-005	8.408E-004	28.29	31.06
14	2.593	65.9	37000	3.570E-005	9.068E-004	29.36	32.23
15	2.625	66.7	38000	3.773E-005	9.584E-004	29.85	32.78
16	2.661	67.6	39000	4.184E-005	1.063E-003	30.45	33.44
17	2.707	68.8	40000	4.658E-005	1.183E-003	31.25	34.31
18	2.731	69.4	40500	4.621E-005	1.174E-003	31.69	34.79
19	2.753	69.9	41000	5.185E-005	1.317E-003	32.08	35.23
20	2.782	70.7	41500	5.372E-005	1.364E-003	32.63	35.83
21	2.839	72.1	42500	5.746E-005	1.459E-003	33.78	37.09
22	2.869	72.9	43000	5.848E-005	1.485E-003	34.41	37.78
23	2.928	74.4	44000	6.069E-005	1.542E-003	35.73	39.23
24	2.960	75.2	44500	6.107E-005	1.551E-003	36.49	40.07
25	2.987	75.9	45000	6.500E-005	1.651E-003	37.16	40.80
26	3.005	76.3	45250	7.078E-005	1.798E-003	37.61	41.30
27	3.037	77.1	45700	8.227E-005	2.090E-003	38.46	42.23
28	3.054	77.6	45900	8.023E-005	2.038E-003	38.92	42.74
29	3.070	78.0	46100	7.893E-005	2.005E-003	39.38	43.23

HSLA-5
R= 0.1
TEMP. AMBIENT
FREQUENCY 5 HZ
ENVIRONMENT AIR

7 PT. POLYNOMIAL FIT

(1ST 3 PTS. FIT BY SECANT METHOD)

OBS.	CRACK LENGTH		CYCLES	DA/DN PER CYCLE		DELTA K	
	IN.	MM.		IN.	MM.	KSI√IN.	MPA√M.
2	2.547	64.7	200000	8.760E-007	2.225E-005	12.88	14.14
3	2.715	69.0	350000	1.074E-006	2.728E-005	14.11	15.50
4	2.947	74.8	450000	1.919E-006	4.874E-005	16.27	17.86
5	3.156	80.2	550000	2.947E-006	7.485E-005	18.85	20.70
6	3.314	84.2	600000	4.602E-006	1.169E-004	21.38	23.48
7	3.445	87.5	625000	7.007E-006	1.780E-004	24.01	26.36
8	3.519	89.4	635000	9.536E-006	2.422E-004	25.76	28.28
9	3.564	90.5	640000	1.137E-005	2.889E-004	26.93	29.56
10	3.620	92.0	645000	1.293E-005	3.284E-004	28.53	31.33
11	3.692	93.8	650000	1.529E-005	3.883E-004	30.81	33.83
12	3.721	94.5	652000	1.748E-005	4.441E-004	31.85	34.97
13	3.753	95.3	654000	2.051E-005	5.210E-004	33.04	36.28
14	3.796	96.4	656000	2.310E-005	5.866E-004	34.78	38.19
15	3.848	97.7	658000	2.395E-005	6.083E-004	37.08	40.71
16	3.899	99.0	660000	2.583E-005	6.561E-004	39.58	43.46
17	3.925	99.7	661000	2.649E-005	6.729E-004	40.94	44.95
18	3.980	101.1	663000	3.343E-005	8.490E-004	44.15	48.47
19	3.989	101.3	664000	4.480E-005	1.138E-003	44.74	49.12

HSLA-6
R= 0.666
TEMP. AMBIENT
FREQUENCY 5 HZ
ENVIRONMENT AIR

7 PT. POLYNOMIAL FIT

(1ST 3 PTS. FIT BY SECANT METHOD)

OBS.	CRACK LENGTH IN.	CRACK LENGTH MM.	CYCLES	DA/DN PER CYCLE IN.	DA/DN PER CYCLE MM.	DELTA K KSI$\sqrt{IN.}$	DELTA K MPA$\sqrt{M.}$
2	1.972	50.1	300000	9.118E-007	2.316E-005	11.03	12.11
3	2.072	52.6	400000	1.097E-006	2.787E-005	11.51	12.64
4	2.257	57.3	500000	1.475E-006	3.747E-005	12.49	13.72
5	2.331	59.2	550000	1.689E-006	4.290E-005	12.93	14.19
6	2.417	61.4	600000	1.952E-006	4.959E-005	13.46	14.78
7	2.514	63.8	650000	2.366E-006	6.010E-005	14.13	15.51
8	2.641	67.1	700000	2.963E-006	7.527E-005	15.11	16.59
9	2.717	69.0	725000	3.509E-006	8.912E-005	15.76	17.31
10	2.809	71.3	750000	4.305E-006	1.093E-004	16.64	18.27
11	2.851	72.4	760000	5.029E-006	1.277E-004	17.08	18.75
12	2.902	73.7	770000	5.653E-006	1.436E-004	17.62	19.35
13	2.959	75.2	780000	6.307E-006	1.602E-004	18.29	20.09
14	3.026	76.9	790000	7.144E-006	1.815E-004	19.15	21.03
15	3.082	78.3	797500	7.961E-006	2.022E-004	19.92	21.87
16	3.124	79.3	802500	8.340E-006	2.118E-004	20.53	22.54
17	3.165	80.4	807500	9.284E-006	2.358E-004	21.17	23.25
18	3.188	81.0	810000	9.840E-006	2.499E-004	21.56	23.67
19	3.240	82.3	815000	1.075E-005	2.730E-004	22.46	24.66
20	3.267	83.0	817500	1.103E-005	2.803E-004	22.95	25.20
21	3.295	83.7	820000	1.127E-005	2.863E-004	23.48	25.78
22	3.319	84.3	822000	1.263E-005	3.207E-004	23.95	26.30
23	3.342	84.9	824000	1.372E-005	3.484E-004	24.43	26.82
24	3.370	85.6	826000	1.548E-005	3.932E-004	25.02	27.47
25	3.403	86.4	828000	1.744E-005	4.430E-004	25.77	28.30
26	3.422	86.9	829000	1.809E-005	4.594E-004	26.22	28.79
27	3.462	87.9	831000	1.816E-005	4.613E-004	27.19	29.85
28	3.479	88.4	832000	1.873E-005	4.757E-004	27.62	30.33
29	3.498	88.8	833000	1.859E-005	4.722E-004	28.13	30.89
30	3.516	89.3	834000	1.918E-005	4.873E-004	28.62	31.43
31	3.534	89.8	835000	1.993E-005	5.062E-004	29.14	32.00
32	3.576	90.8	837000	2.298E-005	5.838E-004	30.39	33.37
33	3.599	91.4	838000	2.496E-005	6.339E-004	31.13	34.18
34	3.625	92.1	839000	2.713E-005	6.892E-004	31.96	35.09
35	3.654	92.8	840000	2.875E-005	7.302E-004	32.98	36.22
36	3.668	93.2	840500	3.139E-005	7.973E-004	33.48	36.76

HSLA
R= 0.1
TEMP. AMBIENT
FREQUENCY 0.5 HZ
ENVIRONMENT 3.5 % NACL

7 PT. POLYNOMIAL FIT

(1ST 3 PTS. FIT BY SECANT METHOD)

OBS.	CRACK LENGTH IN.	CRACK LENGTH MM.	CYCLES	DA/DN PER CYCLE IN.	DA/DN PER CYCLE MM.	DELTA K KSI$\sqrt{IN.}$	DELTA K MPA$\sqrt{M.}$
2	2.352	59.7	395300	2.959E-006	7.517E-005	13.22	14.51
3	2.587	65.7	439100	4.222E-006	1.072E-004	14.87	16.32
4	2.956	75.1	469100	8.828E-006	2.242E-004	18.49	20.30
5	3.057	77.7	481400	1.127E-005	2.863E-004	19.82	21.76
6	3.158	80.2	490000	1.257E-005	3.193E-004	21.34	23.43
7	3.287	83.5	500000	1.532E-005	3.891E-004	23.63	25.94
8	3.365	85.5	505000	1.837E-005	4.666E-004	25.24	27.72
9	3.454	87.7	510000	2.259E-005	5.737E-004	27.35	30.03
10	3.570	90.7	515000	2.884E-005	7.325E-004	30.62	33.62
11	3.644	92.6	517500	3.277E-005	8.324E-004	33.07	36.31
12	3.713	94.3	519500	3.588E-005	9.114E-004	35.68	39.18
13	3.771	95.8	521000	3.755E-005	9.537E-004	38.14	41.88
14	3.806	96.7	522000	4.077E-005	1.036E-003	39.77	43.67
15	3.848	97.7	523000	4.426E-005	1.124E-003	41.85	45.95
16	3.894	98.9	524000	4.845E-005	1.231E-003	44.42	48.77
17	3.919	99.5	524500	4.870E-005	1.237E-003	45.88	50.37
18	3.943	100.2	525000	5.118E-005	1.300E-003	47.43	52.08
19	3.974	100.9	525575	5.561E-005	1.413E-003	49.49	54.34
20	3.997	101.5	526000	6.182E-005	1.570E-003	51.12	56.13
21	4.012	101.9	526250	6.871E-005	1.745E-003	52.25	57.38
22	4.029	102.3	526500	7 460E-005	1.895E-003	53.54	58.79
23	4.050	102.9	526750	8.314E-005	2.112E-003	55.24	60.65
24	4.069	103.3	527000	9.786E-005	2.486E-003	56.81	62.38

HSLA-B
R= 0.666
TEMP. AMBIENT
FREQUENCY 0.5 HZ
ENVIRONMENT 3.5 %NACL

7 PT. POLYNOMIAL FIT

OBS.	CRACK LENGTH		CYCLES	DA/DN PER CYCLE		DELTA K	
	IN.	MM.		IN.	MM.	KSI$\sqrt{\text{IN.}}$	MPA$\sqrt{\text{M}}$
4	2.131	54.1	155000	4.475E-006	1.137E-004	11.88	13.05
5	2.224	56.5	175000	5.364E-006	1.362E-004	12.38	13.59
6	2.305	58.6	190000	6.322E-006	1.606E-004	12.85	14.11
7	2.370	60.2	200000	6.776E-006	1.721E-004	13.24	14.54
8	2.519	64.0	220000	7.838E-006	1.991E-004	14.26	15.66
9	2.562	65.1	225000	8.177E-006	2.077E-004	14.58	16.01
10	2.689	68.3	240000	9.167E-006	2.329E-004	15.61	17.14
11	2.780	70.6	250000	1.082E-005	2.748E-004	16.46	18.07
12	2.833	72.0	255000	1.271E-005	3.230E-004	17.00	18.66
13	2.896	73.6	260000	1.490E-005	3.786E-004	17.63	19.41
14	2.974	75.5	265000	1.704E-005	4.327E-004	18.60	20.43
15	3.020	76.7	267500	1.721E-005	4.371E-004	19.19	21.07
16	3.093	78.6	271500	1.719E-005	4.366E-004	20.21	22.19
17	3.132	79.6	273500	1.751E-005	4.448E-004	20.80	22.84
18	3.182	80.8	276500	1.921E-005	4.880E-004	21.59	23.71
19	3.218	81.7	278500	2.464E-005	6.258E-004	22.20	24.38
20	3.241	82.3	279500	2.670E-005	6.782E-004	22.62	24.84
21	3.270	83.1	280500	2.680E-005	6.808E-004	23.15	25.42
22	3.302	83.9	281500	2.979E-005	7.567E-004	23.76	26.09
23	3.329	84.6	282500	3.076E-005	7.812E-004	24.32	26.71